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NATURAL NOISE FIELDS FROM 1 C/S TO 100 KC/S

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DECO Electronics, Inc.

Boston Boulder Leesburg Santa Monica Washington

NATURAL NOISE FIELDS FROM 1 C/S TO 100 KC/S

By

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ABSTRACT

Vertical electric and horizontal magnetic rms noise field intensities have recently been measured over the frequency range of 30 to 50,000 c/s for all seasons of the year and for all time blocks. This data is combined with that of other workers in the field to present the natural noise density spectra from 1 c/s to 100 kc/s for central United States regions. The portion of the data between 10 and 100 kc/s is found to be in close agreement with C. C. I. R. Report No. 65, "Revision of Atmospheric Radio Noise Data." Seasonal and diurnal variations at these locations are seen to become small below 1 kc/s.

In addition to rms data, measurements were made of the peak envelope occurring within 5-minute time intervals in a 7 c/s bandwidth. Under certain conditions, rapid changes in the rms to peak envelope dynamic range were noted between 3 and 8 kc/s. This phenomena is discussed with respect to source characteristics and propagation.

1. INTRODUCTION

DECO Electronics, Inc. has been carrying on a research program aimed at determining the characteristics of natural noise fields at extremely low frequencies (ELF). These measurements were extended to frequencies in the very low frequency (VLF) region in the interest of comparing the ELF data with the wealth of data available at VLF.

A brief discussion of instrumentation used for these measurements is followed by a description of the data obtained during 1962.

2. INSTRUMENTATION

Figure 1 is a block diagram of the instrumentation used throughout these measurements. The whip antenna which was used for most of the measurements being reported has a physical height of 8.85 meters. The effective electrical height of the whip-coupler combination is 1.5 meters. Some data was occasionally taken with loop antennas of the horizontal magnetic field intensity. The description of these loops is given in Figure 1.

A H. P. 302-A wave analyzer was used as the field intensity instrument for these measurements. This wave analyzer has a 3 db bandwidth of 7 c/s and a frequency range of 20 c/s to 50 kc/s. Its output was metered with an average reading rms calibrated H. P. 403-A voltmeter whose 1 c/s response provided the dampening required to permit visual reading of a quasi-rms noise intensity.* This "eye-balling" method of obtaining rms values for noise fields is not extremely accurate but the results indicate errors less

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* An average reading rms calibrated voltmeter will read, rms/0.9 $\left(\frac{e_{rms}}{e_{ave}}\right)$ where $\left(\frac{e_{rms}}{e_{ave}}\right)$ is the indicated ratio for the particular noise being measured and, for example, equals 1.256 for Gaussian noise.

than a few db. The peak detector measured the peak envelope voltage reached during each 5-minute measurement period. This provides us with some indication of the characteristics of the noise since we now have the ability to obtain the rms to peak envelope dynamic range in a 7 cycle per second bandwidth.

The measurement sites were very carefully selected in remote areas to eliminate or minimize the signals from 60 cycle per second power lines and harmonics. At the Colorado site, approximately 40 miles east of Boulder, Colorado, the site was separated from even small power lines by a distance of 2 to 3 miles in all directions. A small 60 c/s signal was evident at this location but no harmonics could be seen against the atmospheric noise background in a 7 c/s bandwidth. At the California site, approximately 150 miles south of San Francisco in the Los Padres National Forest, the 60 c/s signal was approximately 15 db below atmospheric noise in a 1 c/s bandwidth. This value was obtained with synchronous detection techniques.

The calibration of the antennas was carefully calculated with standard techniques and then checked and cross-checked against other antennas of known effective height and against known fields in the VLF frequency region.

3. RESULTS

Figures 2 through 12 are a selection of natural noise density curves for selected seasons and time blocks in the Colorado and California regions. The data has been normalized to a 1 c/s effective bandwidth and plotted in db relative to 1 microvolt per meter per sq. root cycle per second and 1 microamp per meter per sq. root cycle per second.

The data obtained with loop antennas when compared with vertical E measurements obtained with the whip antenna indicated that in general the ratio $E_v/H_h = 377$ ohms. That is, the vertical E to horizontal H relationship is approximately that of a plane wave throughout this frequency range. Some anomalies between 300 c/s and 3,000 c/s were noted. These anomalies indicated $E_v/H_h > 377$ ohms. Sufficient repeatable measurements have not been obtained, however, to establish the characteristics of these anomalies.

Each figure contains a solid curve in the frequency range 10 kc/s to 100 kc/s obtained from C. C. I. R. Report 65 [1]. This is the predicted median values for the rms natural noise fields for the season, time block and region presented. In general, the predicted values are somewhat higher in the 10 kc/s region than the measured values.

Data from other sources was used when possible to extend the frequency range down to approximately 1 c/s [2].

In general a decrease in diurnal, seasonal and regional variations are noted below 1 kc/s. This is to be expected because of the decreasing propagation attenuation at these frequencies. The greatest diurnal, seasonal and regional variations are noted in the frequency region between 1 kc/s and 10 kc/s. This is also to be expected since this is the region of highest attenuation for the predominant waveguide modes [3, 4]. The dip produced by this waveguide cutoff is seen to vary from a maximum of approximately 40 db to a minimum of less than 10 db. It is especially interesting to note that this minimum value does not occur at exactly the same frequency for the different seasons and time blocks. It is seen to shift from a low frequency of 2 kc/s to a high of approximately 7 kc/s. This can undoubtedly be partially accounted for by changing ionospheric conditions. It was in this frequency range that the greatest anomaly in the E_v/H_h ratio was noted.

3.1 Winter Data

Very little winter data has been obtained to date. Only one curve, Figure 2, for the time block 1200 to 1600 hours in Colorado is given in this report. It is of interest primarily in the comparison obtained between data taken in 1957 by Watt and Maxwell [4] and data obtained in 1959 by Elwood Maple [2]. Very good comparison is evident.

3.2 Spring Data

Figures 3 to 5 present data obtained during the spring season in Colorado for time blocks 0800 to 1200, 1600 to 2000, and 2000 to 0400. No special mention is deserving except to note the shift in the frequency at which the null occurs. Figure 3, late morning data, shows this null occurring at approximately 6 kc/s. During afternoon and early evening hours it has shifted back to approximately 3 kc/s. The nighttime data indicates the frequency midway between these two extremes.

3.3 Summer Data

Figures 6 through 9 provide a comparison of data obtained in two regions for the summer season and a comparison of several time blocks. These figures indicate similar shifts in the null frequency as that noted in the spring data although the change is not as pronounced. The nearly 40 db change in noise density noted between 10 kc/s and 2 to 3 kc/s in Figure 6 is indicative of an area far removed from local thunderstorm activity. The magnitude of this change is seen to decrease in Figure 8. This might be expected since late evening and nighttime hours usually produce considerable thunderstorm activity in the southern United States, Mexico, and Central America. This very deep null at the San Francisco region can possibly be partially attributed to the very low man-made noise level at this site. A comparison of Figures 6 and 9 emphasizes the difference in local thunderstorm activity for the Colorado and San Francisco regions. The excellent agreement between the C.C.I.R. predictions and the VLF and LF data for the summer season is to be noted.

3.4 Fall Data

Figures 10 through 12 present data obtained for the fall season in the Colorado region. This data follows the same pattern noted for spring and summer data in that the null for the 0800 to 1200 time block is occurring at a higher frequency than the other time blocks. The data is typical in other respects and agrees quite well with C.C.I.R. predictions.

3.5 Dynamic Range Data

Dynamic range data is presented only for the spring and summer seasons. The variations in dynamic range are particularly interesting but also particularly difficult to explain. The following differences in the source and propagation characteristics over this wide frequency range should be kept in mind when examining these figures. The predominant noise source throughout the frequency range for which dynamic range data was obtained is lightning discharges. A brief summary of the characteristics of lightning discharges is therefore in order. A lightning stroke is seen to consist of three main sections each of which produce energy in a different frequency range [5-7]. The predischarge consists of a series of leaders each about 1 microsecond long, separated by about 25 to 100 microseconds, for a total period in the order of 500 to 1000 microseconds. This is followed by the main discharge or return stroke occurring for a time of about 100 microseconds. In recent years it has been discovered that this return stroke is often followed by what is commonly called the slow tail consisting of a few hundred amperes of current flowing for up to half a second. The average current flow for each predischarge leader is approximately 300 amps and produces most of the energy in the 30 to 100 kc/s frequency region. The main discharge may have a peak value of 30 kiloamps or greater. This main discharge has an energy spectrum peak around 9 to 10 kc/s. The slow tail is of course the source of ELF noise. It is interesting to note that for a given distribution of lightning discharges the main strokes will have the largest time interval spacings. The individual leaders are closely spaced and the energy therefrom might be expected to blend together or overlap. A similar situation would be expected for the slow tails producing the ELF energy. We might, therefore, expect the maximum rms to peak envelope dynamic range to occur at VLF frequencies.

We must also consider, however, the effects of propagation of the dynamic range variations. Figure 13 shows a plot of attenuation coefficient versus frequency [3, 8, 9, 10]. It would be expected that propagation characteristics will tend to reduce the dynamic range at frequencies having the lowest attenuation. This results because of the greater effective number of noise sources and the effect of overlapping signals from these lightning discharges. During periods of local thunderstorm activity then, it might be expected that the greater dynamic range would occur between 1 and 10 kc/s. Whether the high attenuation around 3 kc/s or the high peak energy and wide spacing charactersitics of the source around 9 to 10 kc/s will be predominant in producing the peak dynamic range will depend upon the actual source and attenuation characteristics at the time. Without further discussion we will examine the dynamic range data.

Figures 14 and 15 show a shift in the peak dynamic range for the same time block but different seasons from approximately 7 kc/s in the spring down to approximately 2.5 kc/s during the summer. It is interesting to note the very similar characteristics between dynamic range for this 1200 - 1600 hours time block in the summer season in the Colorado and San Francisco regions. Figure 16, dynamic range for the 0800 to 1200 time block in the San Francisco region is particularly interesting when compared with Figure 6, the noise density curve for the same time

time block, region and season. The very deep null noted in the noise density curve indicates few local thunderstorms. If a few local thunderstorms did exist at this time, however, it would be expected to produce a very large dynamic range at these frequencies; Figure 16 bears out this analysis.

Figure 17 is typical of dynamic range noted for late evening and early morning hours. Figure 18 illustrates the variations that might be expected in the presence and absence of local thunderstorms. Thunderheads were visible on the horizon when the data marked, "local thunderstorm" was taken.

Complete data for all seasons and all time blocks will soon be available for the Colorado region. Additional measurements to include arctic and tropical regions are planned in the near future.

ACKNOWLEDGMENTS

The authors wish to express their gratitude for the encouragement and advice received from Mr. A. D. Watt and to David Reimer for assistance in the measurements.

REFERENCES

[1] C.C.I.R. Study, Group VI, "Report on Revision of Atmospheric Radio Noise Data," 1957.

[2] Elwood Maple, private communication.

[3] J. R. Wait, "The Attenuation vs. Frequency Characteristics of VLF Radio Waves," Proc. IRE, Vol. 45, No. 6, p. 768, 1957.

[4] A. D. Watt and E. L. Maxwell, "Characteristics of Atmospheric Noise from 1 to 100 kc," Proc. IRE, Vol. 45, No. 6, p. 787,1957.

[5] B. F. J. Schonland, et al., "Progressive Lightning V, A Comparison of Photographic and Electrical Studies of the Discharge Process," Proc. Roy. Soc. (London) [A] 166, pp. 56-75, 1938.

[6] A. D. Watt, "ELF Electric Fields from Thunderstorms," J. Research NBS, 64D, 425, 1960.

[7] A. G. Jean, et al., "Observed Attenuation Rate of ELF Radio Waves," J. Research, NBS, 65D, Sept - Oct 1961.

[8] T. L. Eckersley, "Studies in Radio Transmission," J. I.E.E., Vol. 27, pp. 405-459, Sept. 1932.

[9] J. A. Pierce, "Sky-wave Field Intensity, I. Low-and Very Low-Radio Frequencies," Tech. Rep. No. 158, Cruft Lab. Harvard University, Cambridge, Mass., Sept. 1, 1952.

[10] F. W. Chapman and R. C. V. Macario, "Propagation of Audio Frequency Radio Waves to Great Distances," Nature 177, p. 930, 1956.

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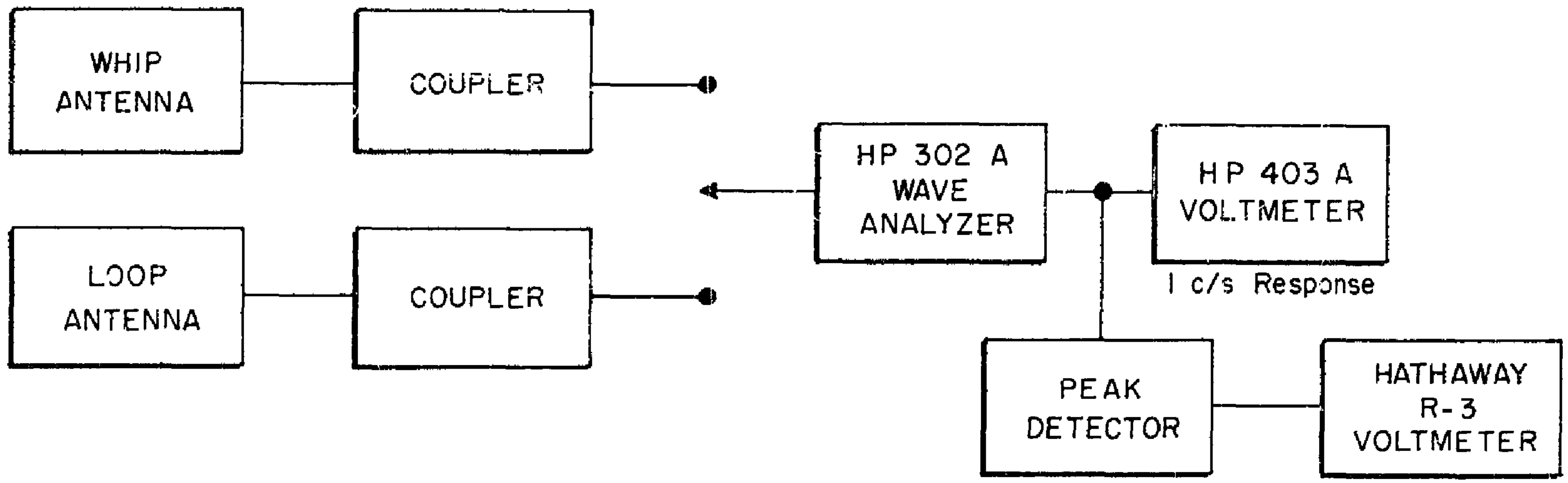

ANTENNAS USED:

Loops

1 Meter Square; 500 Turn;---- Frequency Range 300 - 7,000 c/s

1 Meter Square; 12 Turn;---- Frequency Range 10,000-50,000 c/s

Vertical Whip

Height -29 Feet --------------- Frequency Range 20-50,000 c/s

Figure 1 EQUIPMENT BLOCK DIAGRAM

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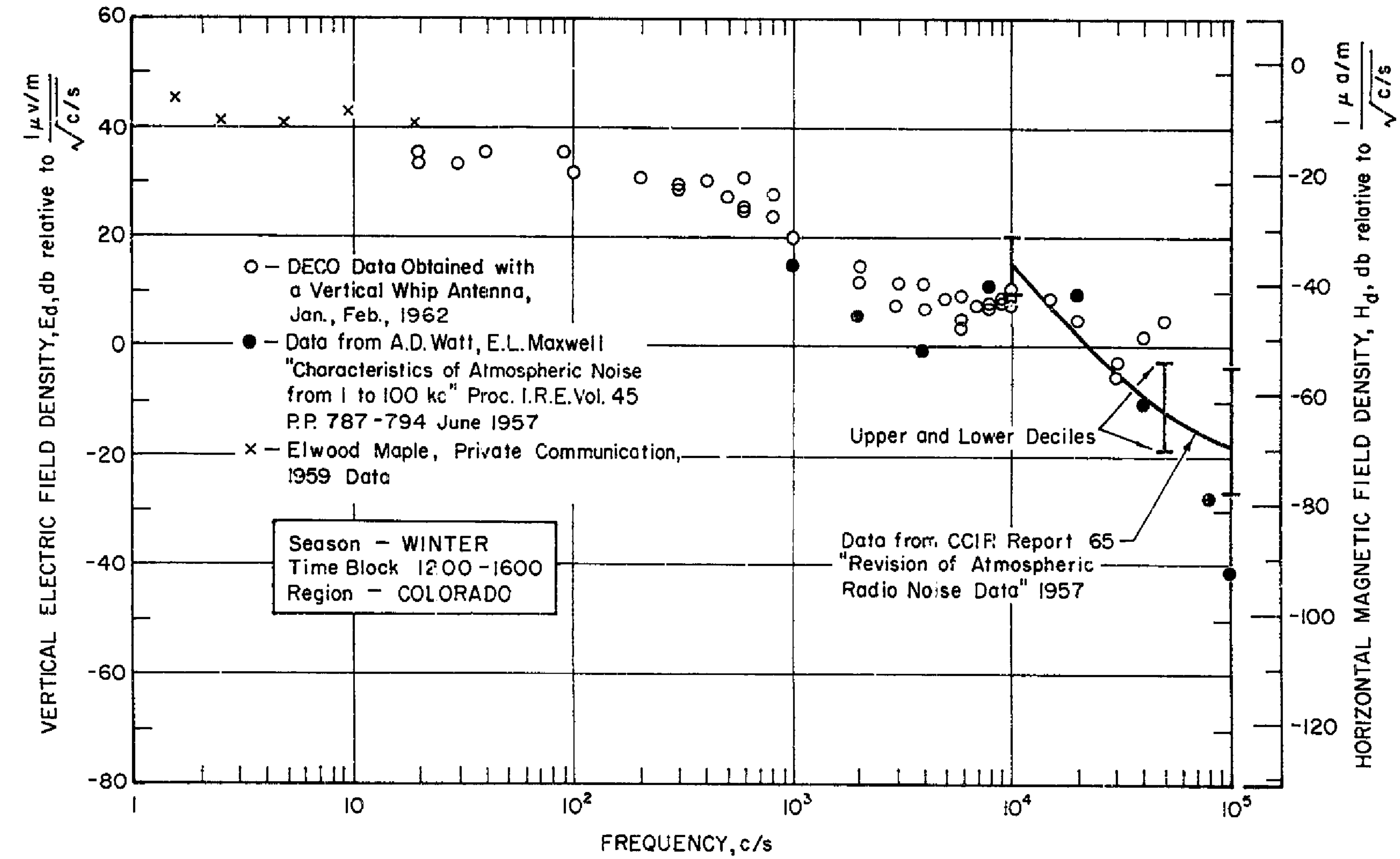

Figure 2 NATURAL NOISE DENSITY SPECTRA

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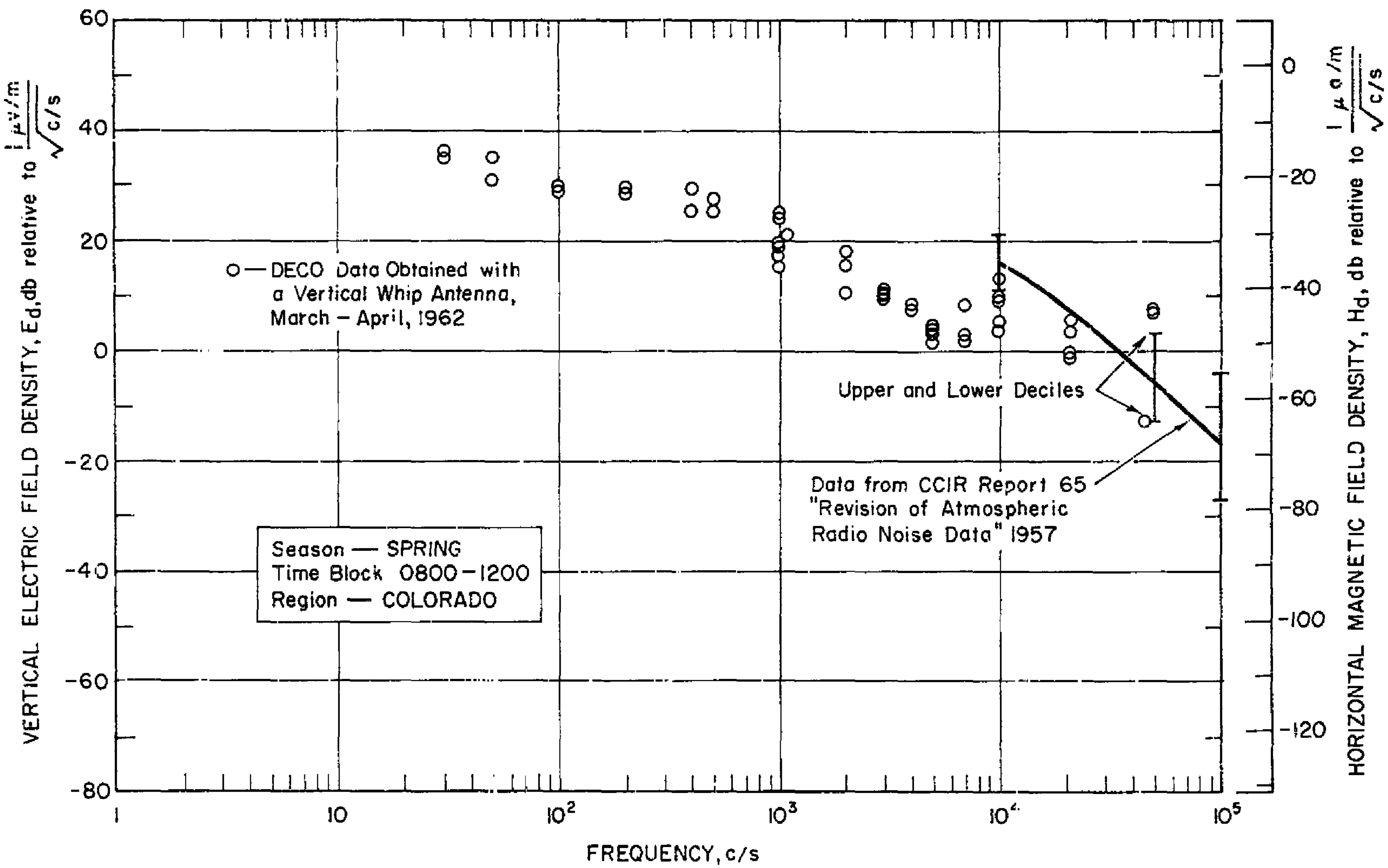

Figure 3 NATURAL NOISE DENSITY SPECTRA

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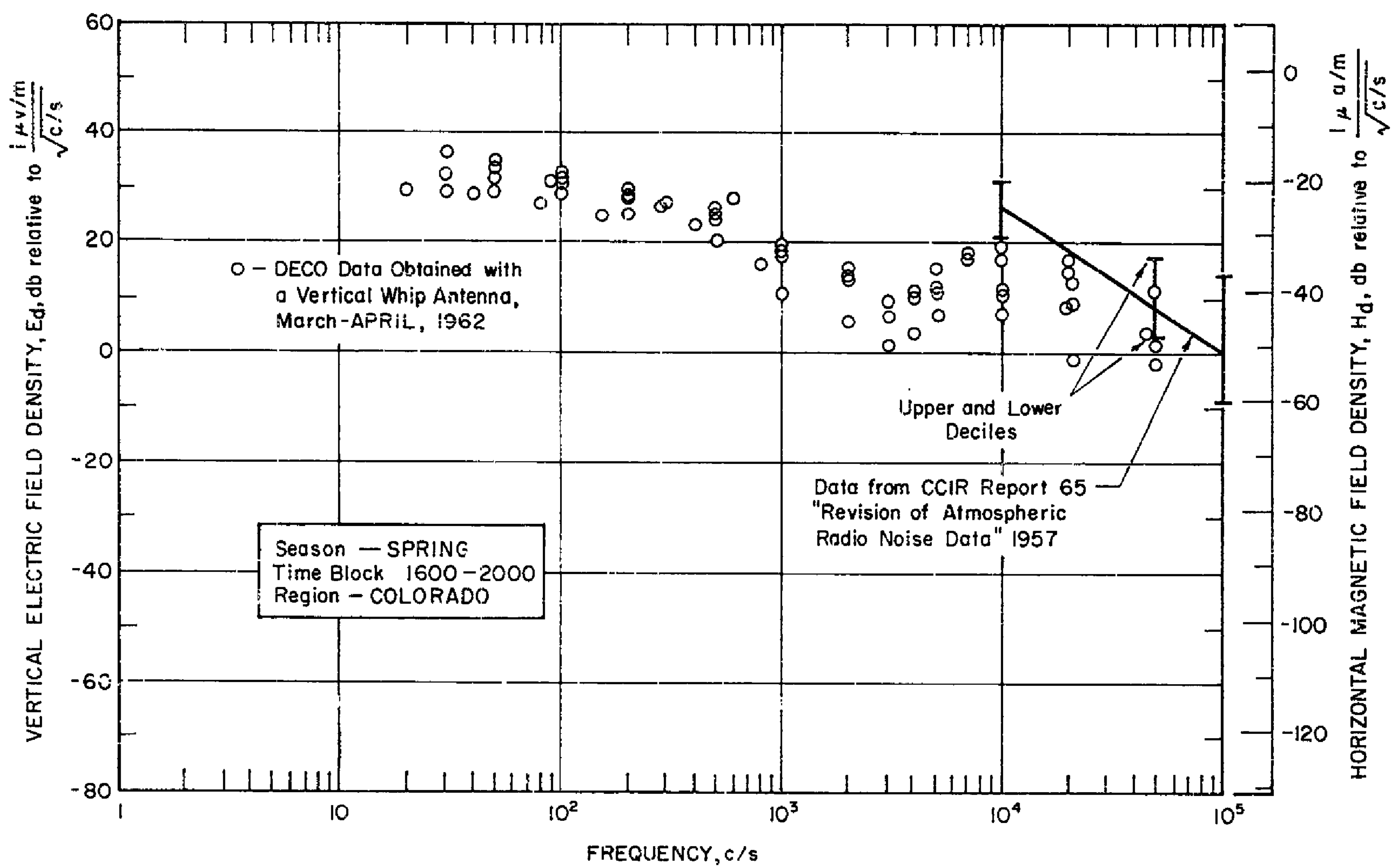

Figure 4 NATURAL NOISE DENSITY SPECTRA

DECO 30 F 3 621205 E

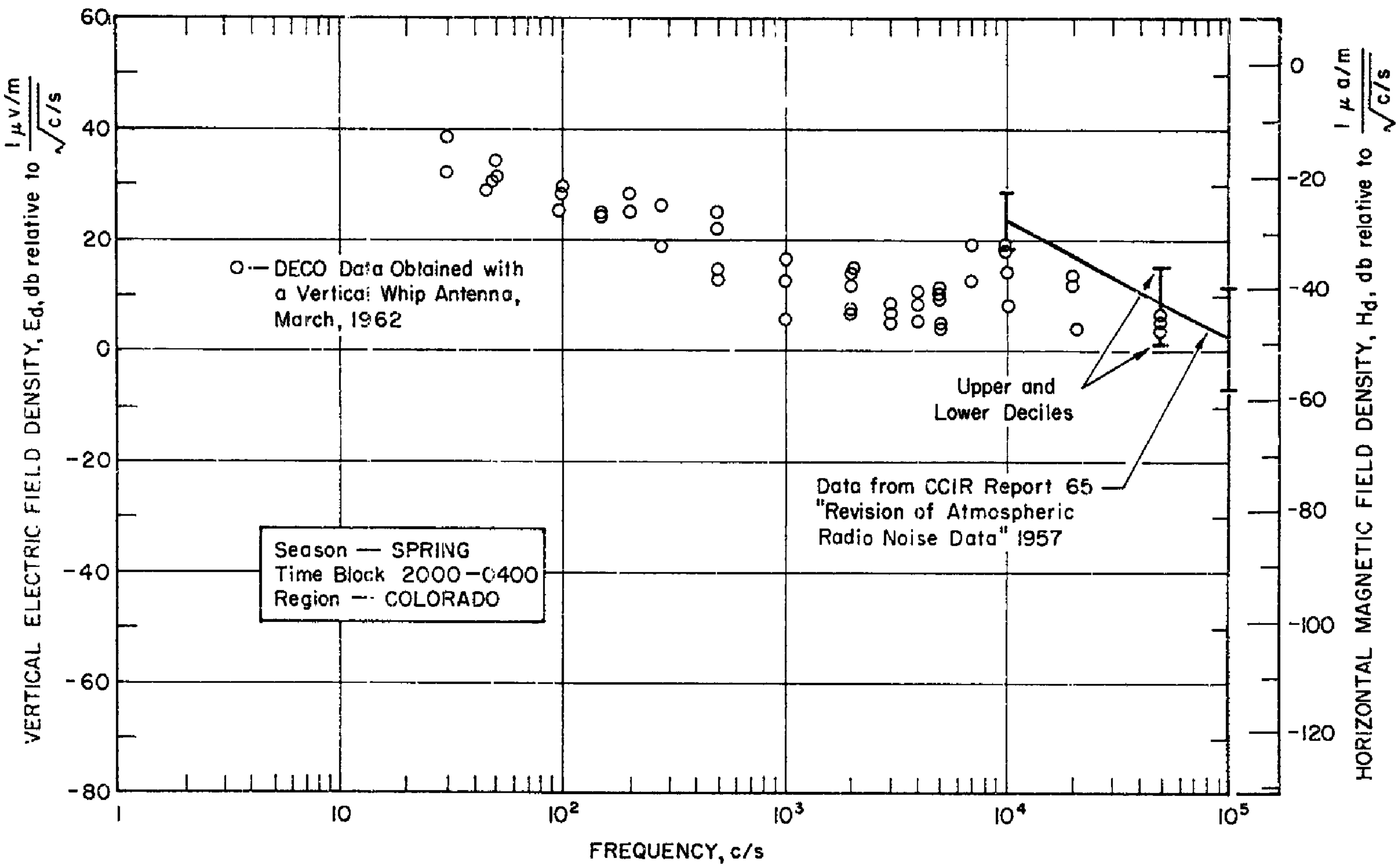

Figure 5 NATURAL NOISE DENSITY SPECTRA

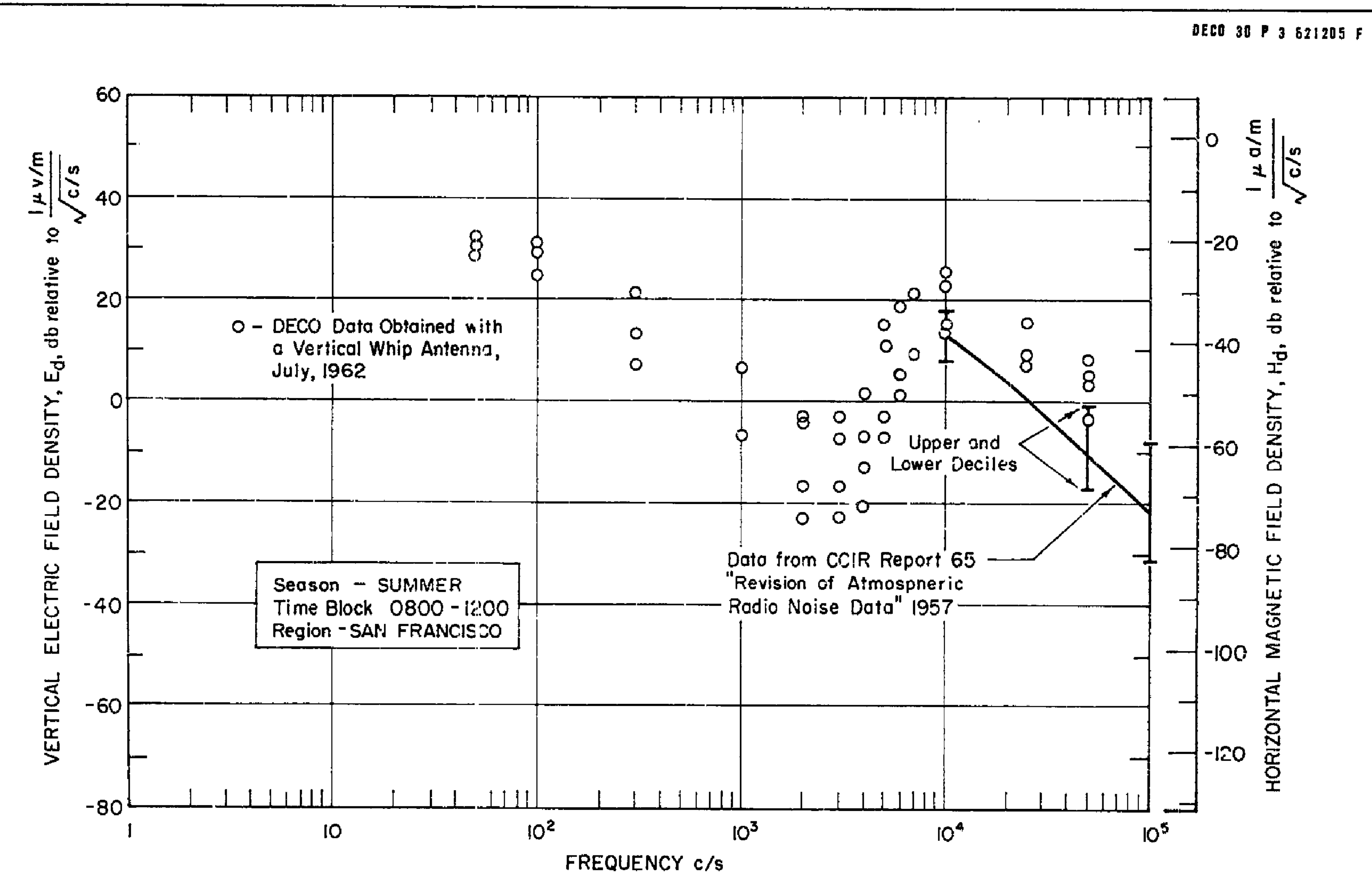

Figure 6 NATURAL NOISE DENSITY SPECTRA

DECO 30 P 3 621205 G

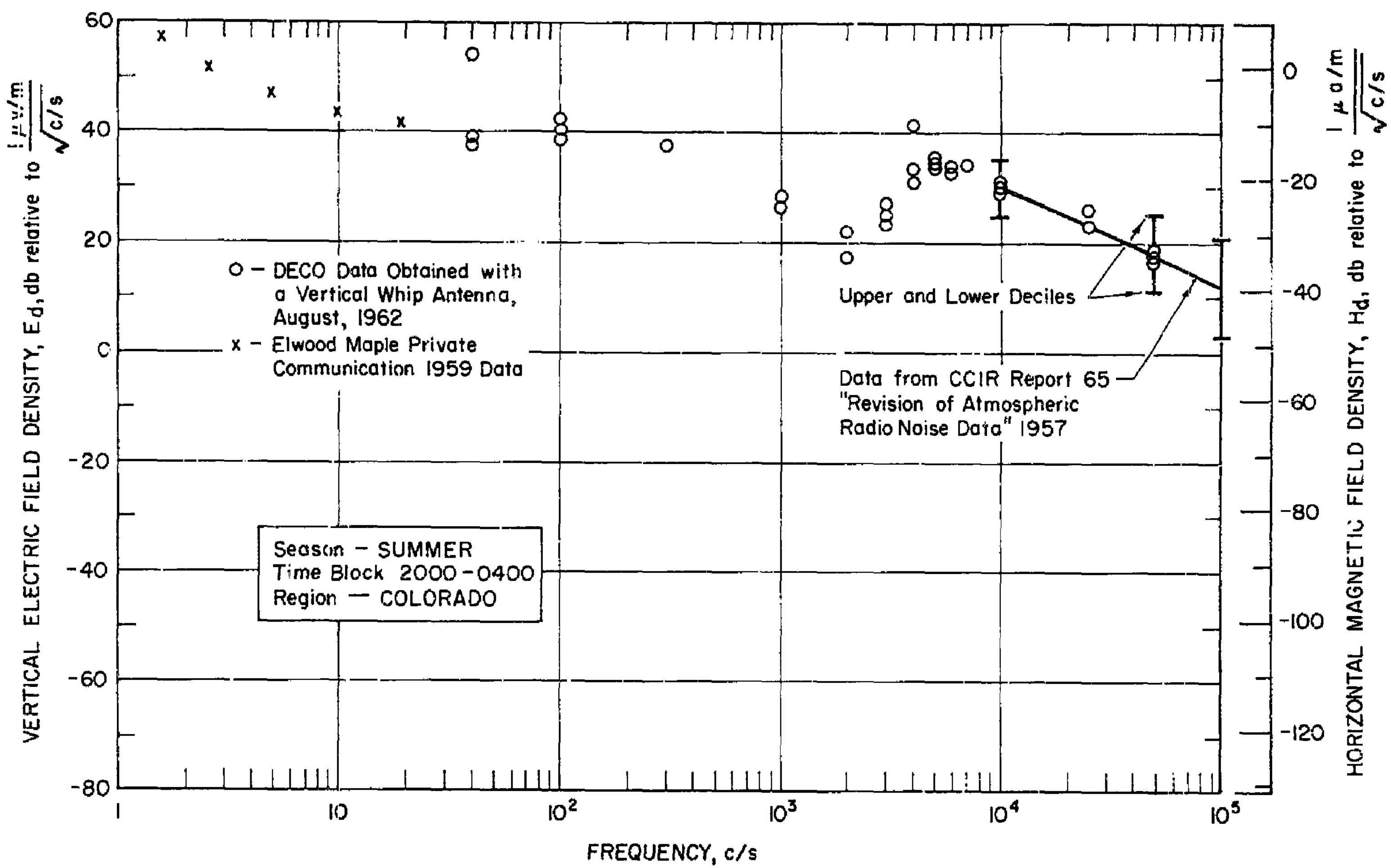

Figure 7 NATURAL NOISE DENSITY SPECTRA

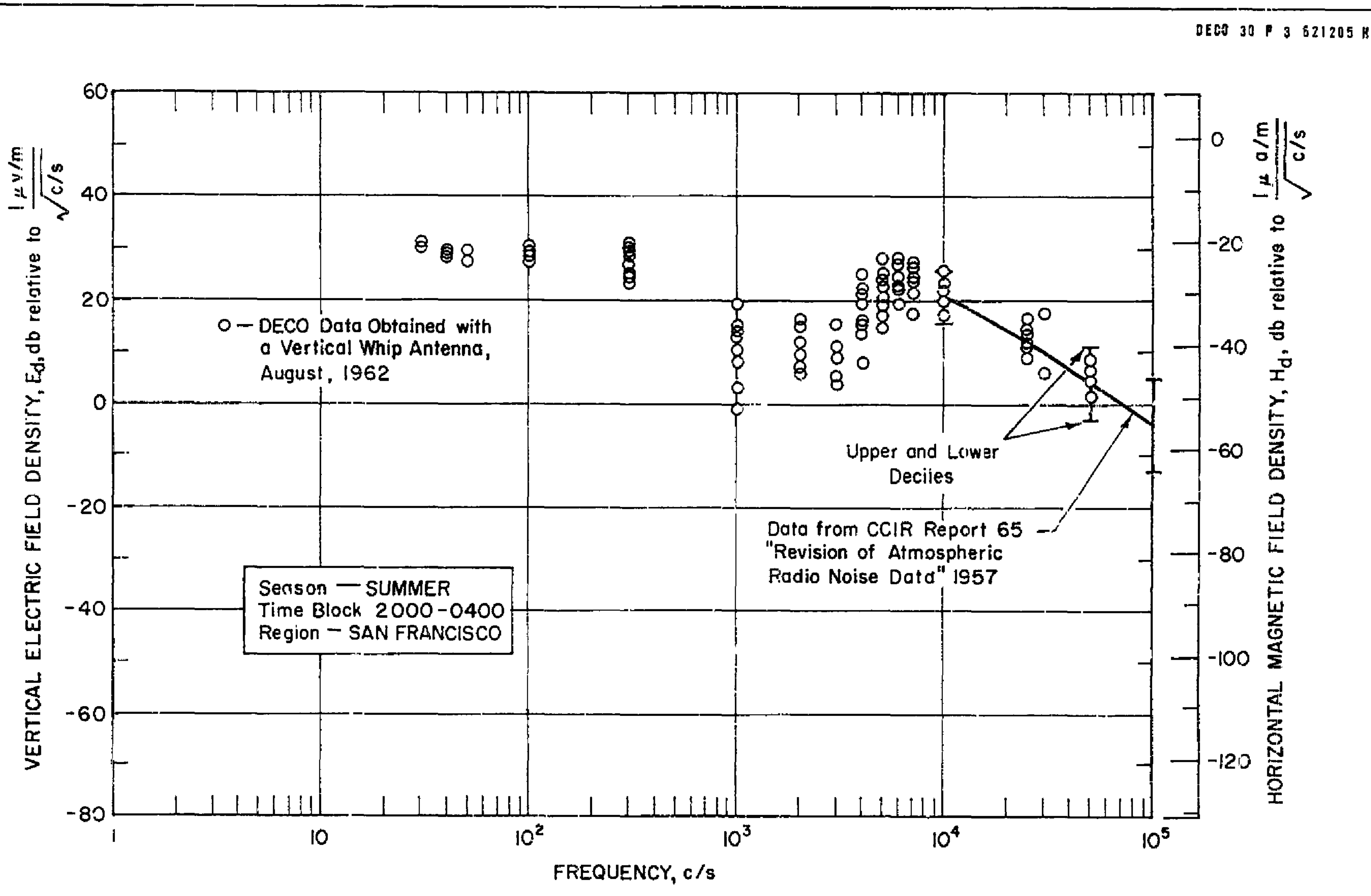

Figure 8 NATURAL NOISE DENSITY SPECTRA

DECO 30 P 3 521205 1

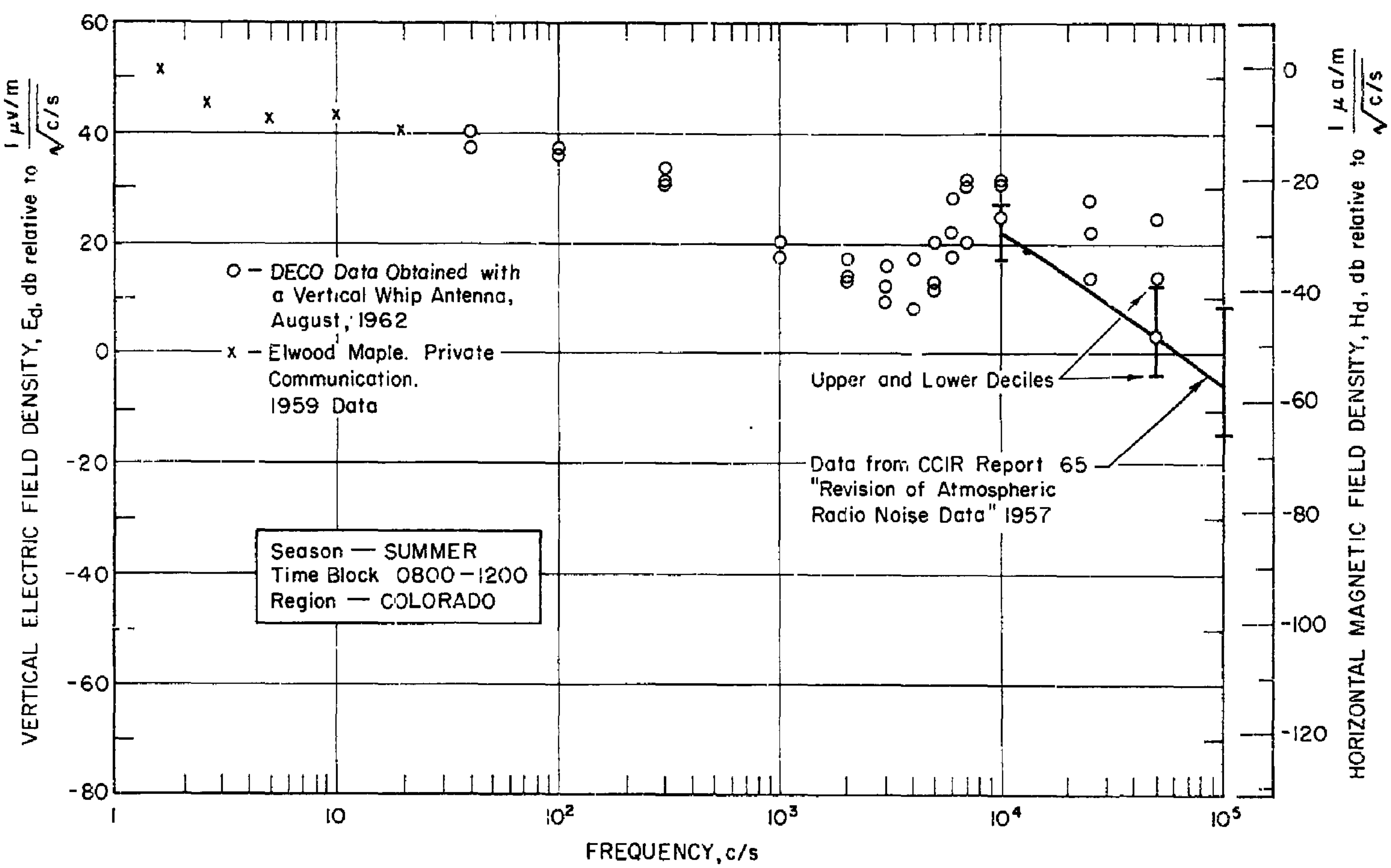

Figure 5 NATURAL NOISE DENSITY SPECTRA

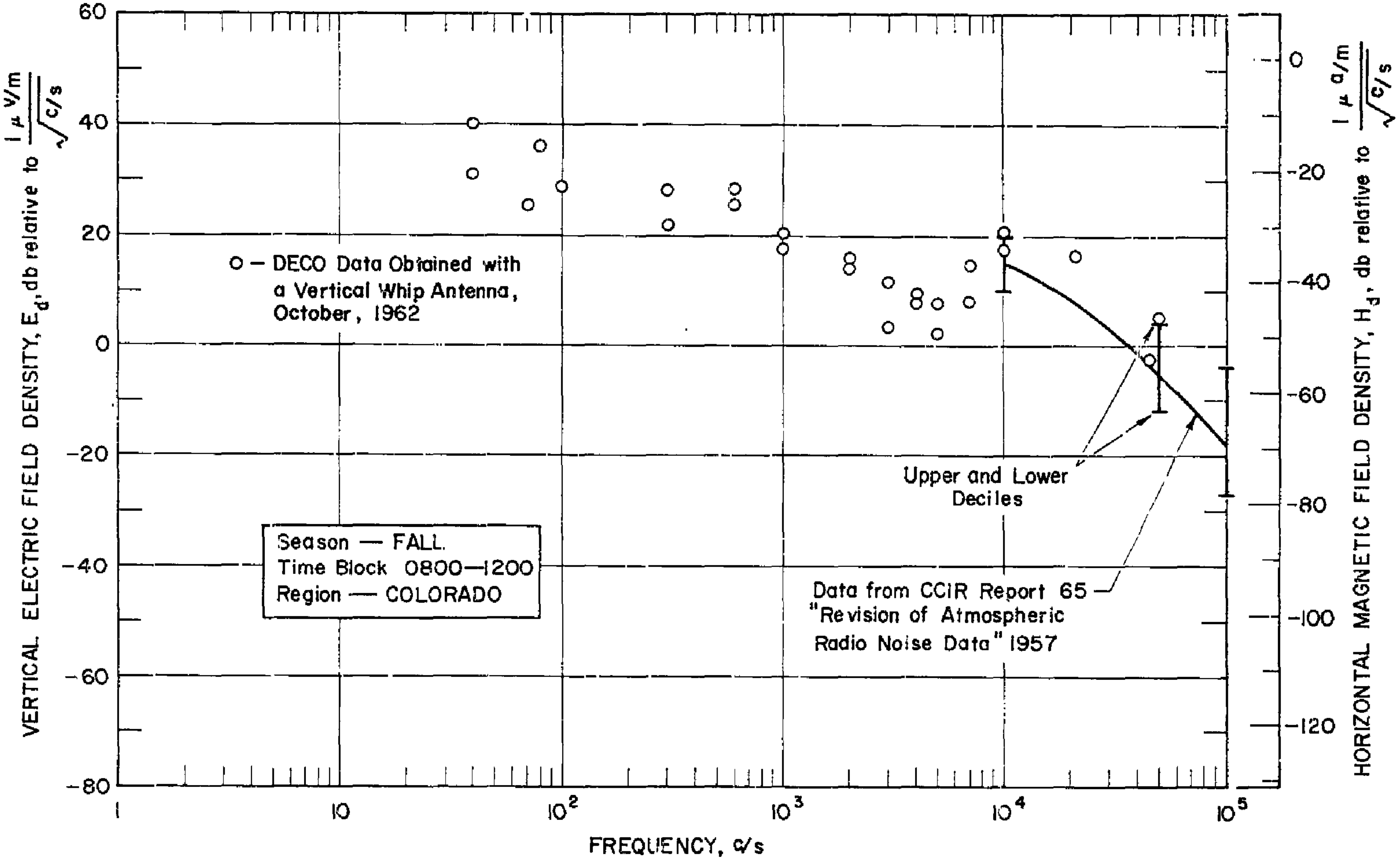

Figure 10 NATURAL NOISE DENSITY SPECTRA

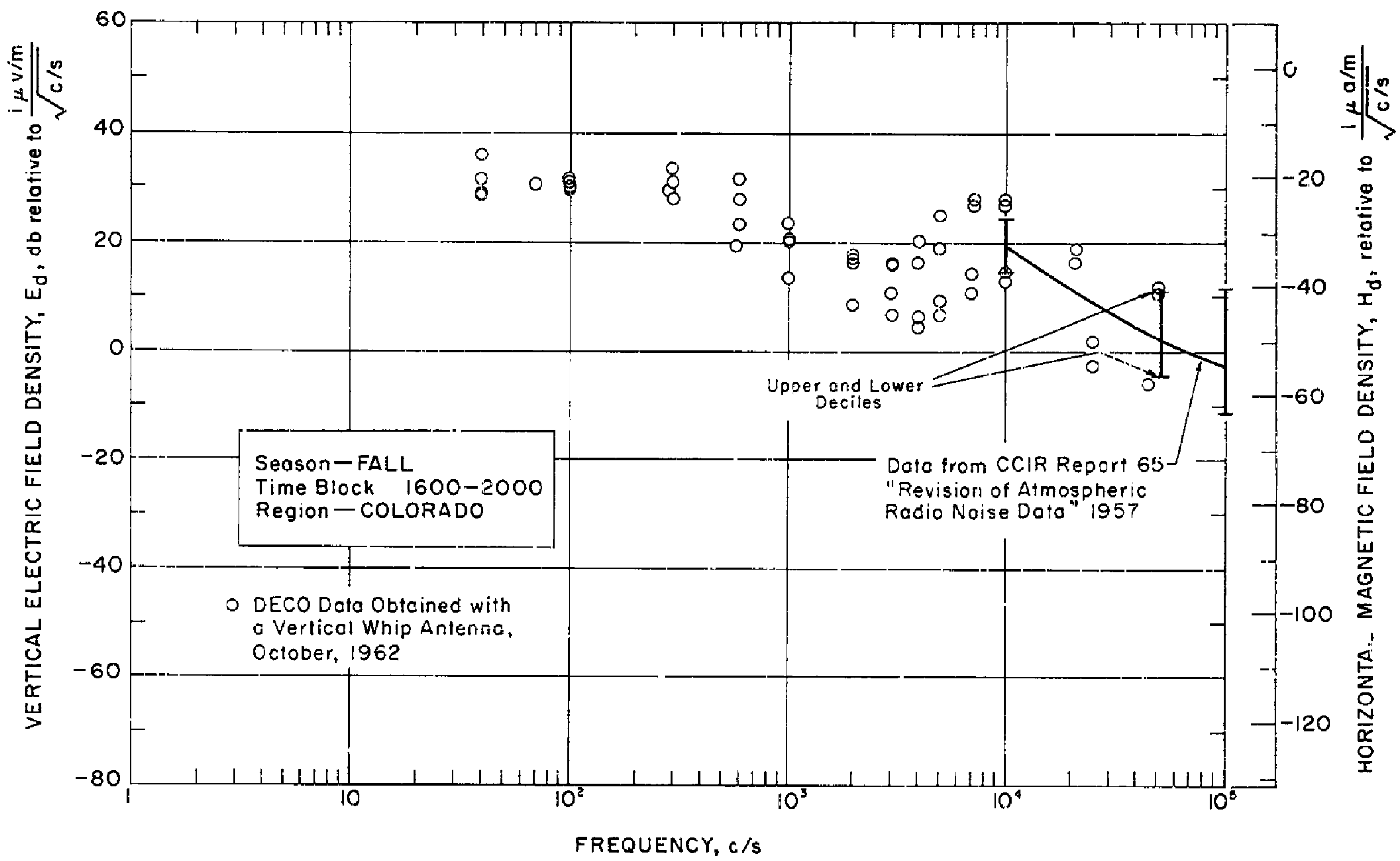

Figure 11 NATURAL NOISE DENSITY SPECTRA

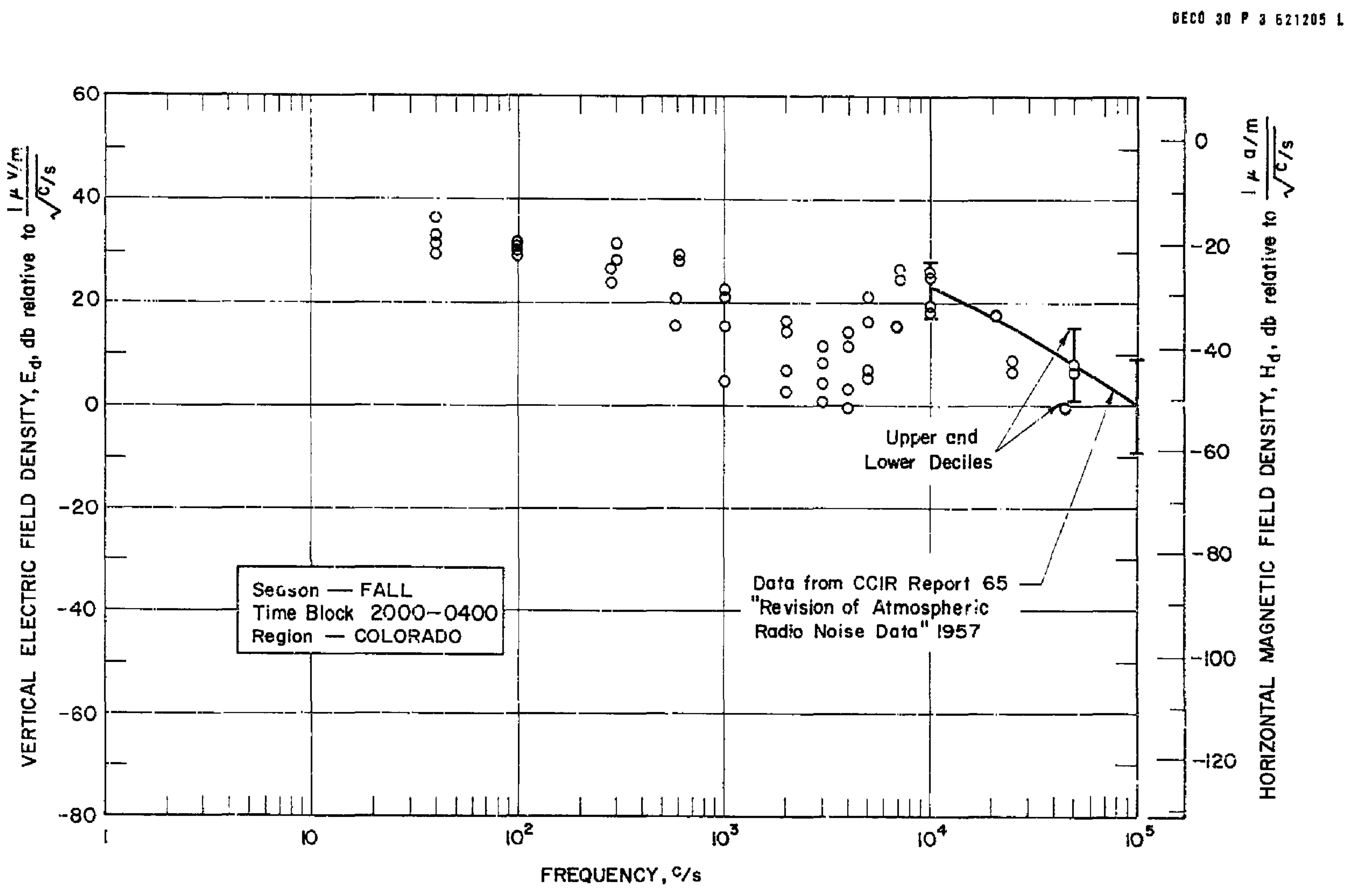

Figure 12 NATURAL NOISE DENSITY SPECTRA

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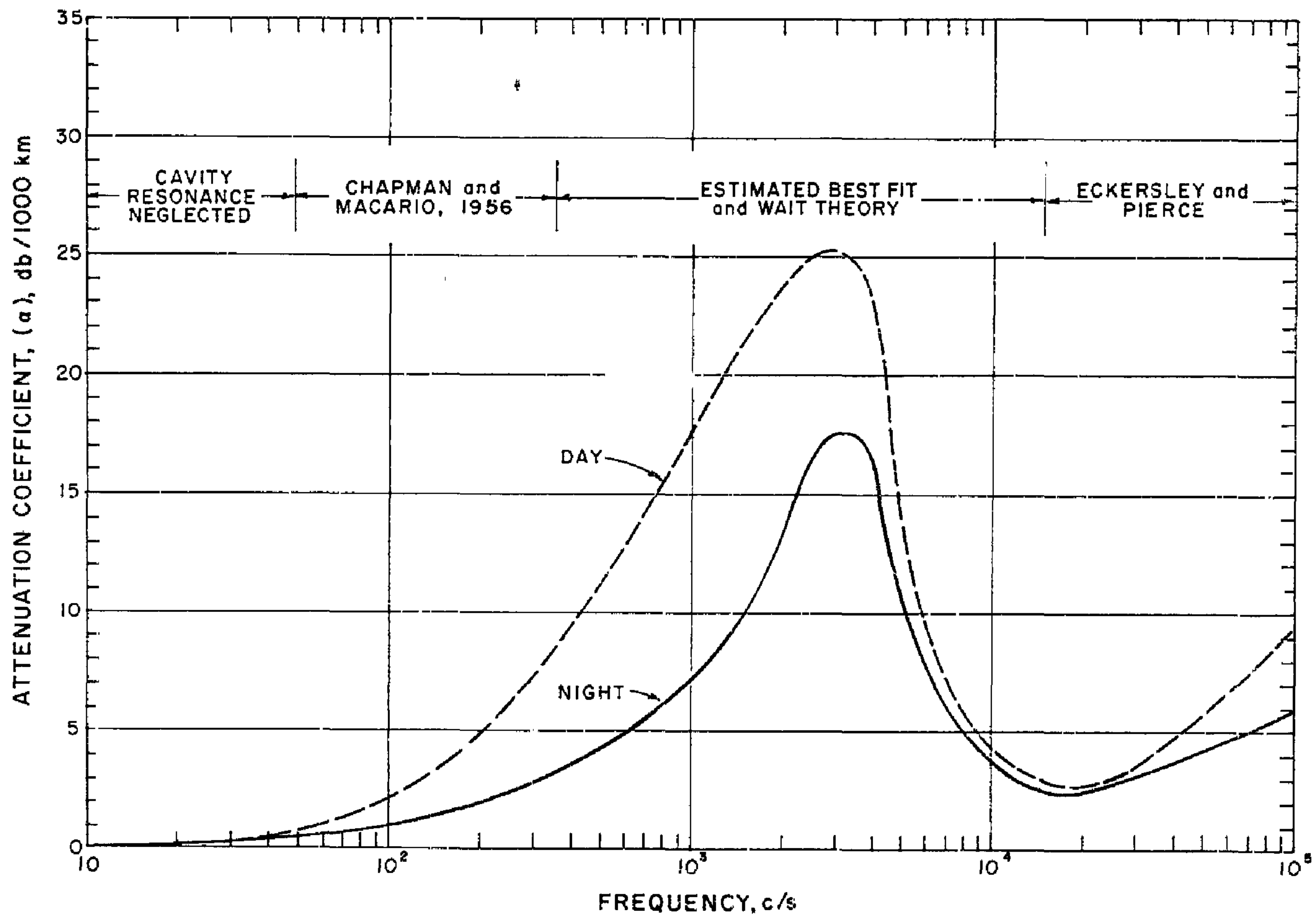

Figure 13 ATTENUATION COEFFICIENT

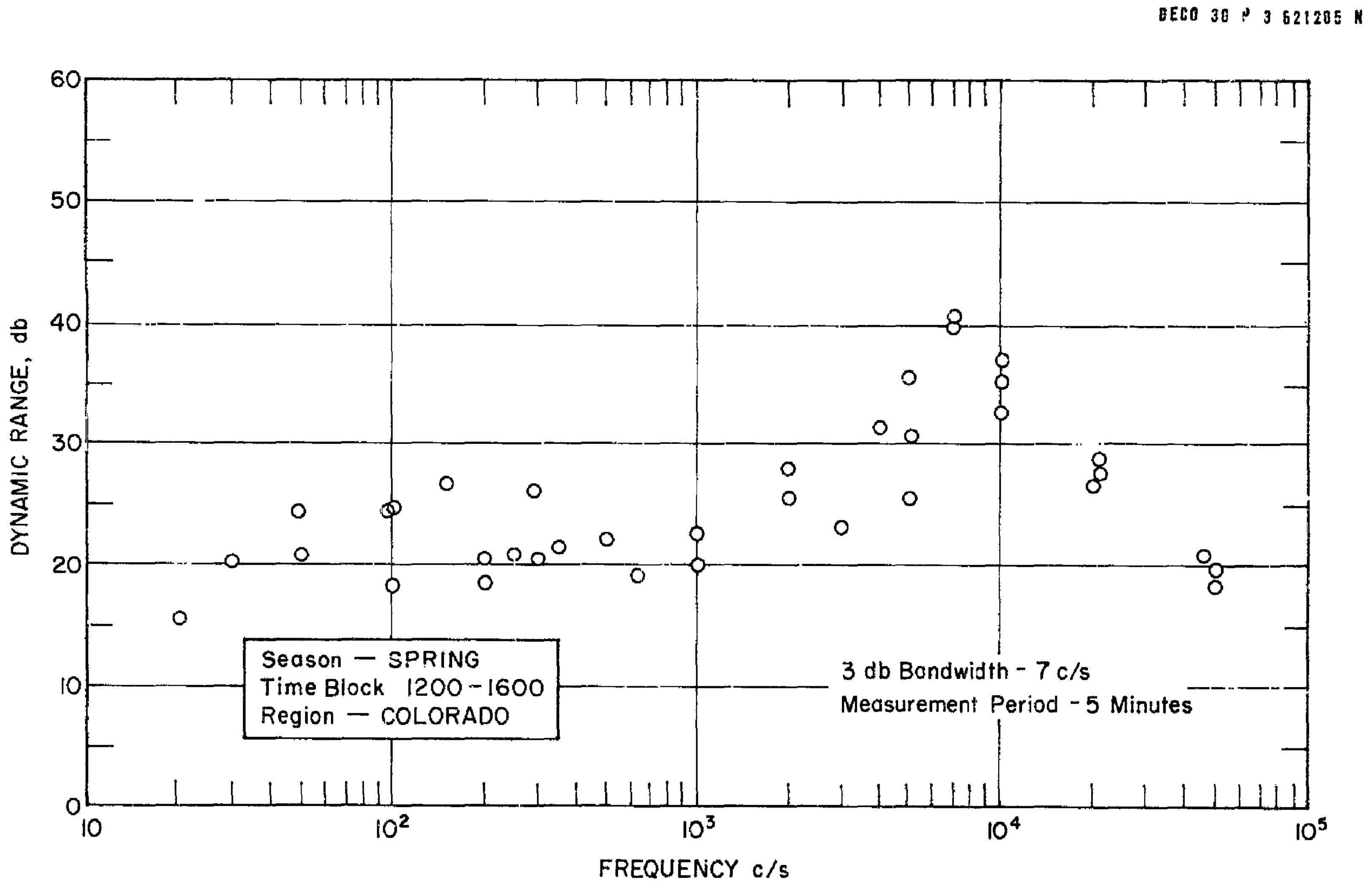

Figure 14 DYNAMIC RANGE; RMS TO PEAK ENVELOPE

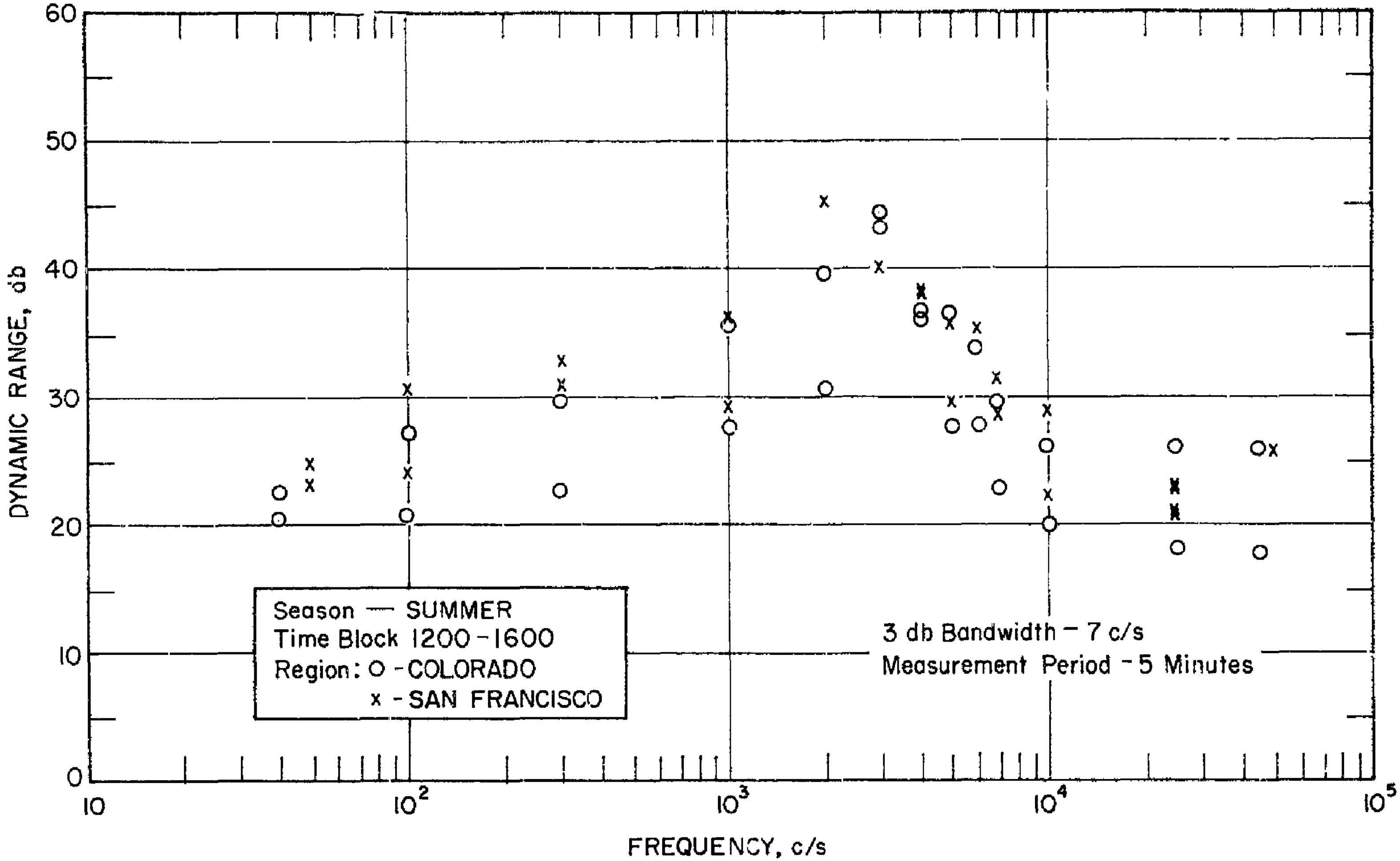

Figure 15 DYNAMIC RANGE; RMS TO PEAK ENVELOPE

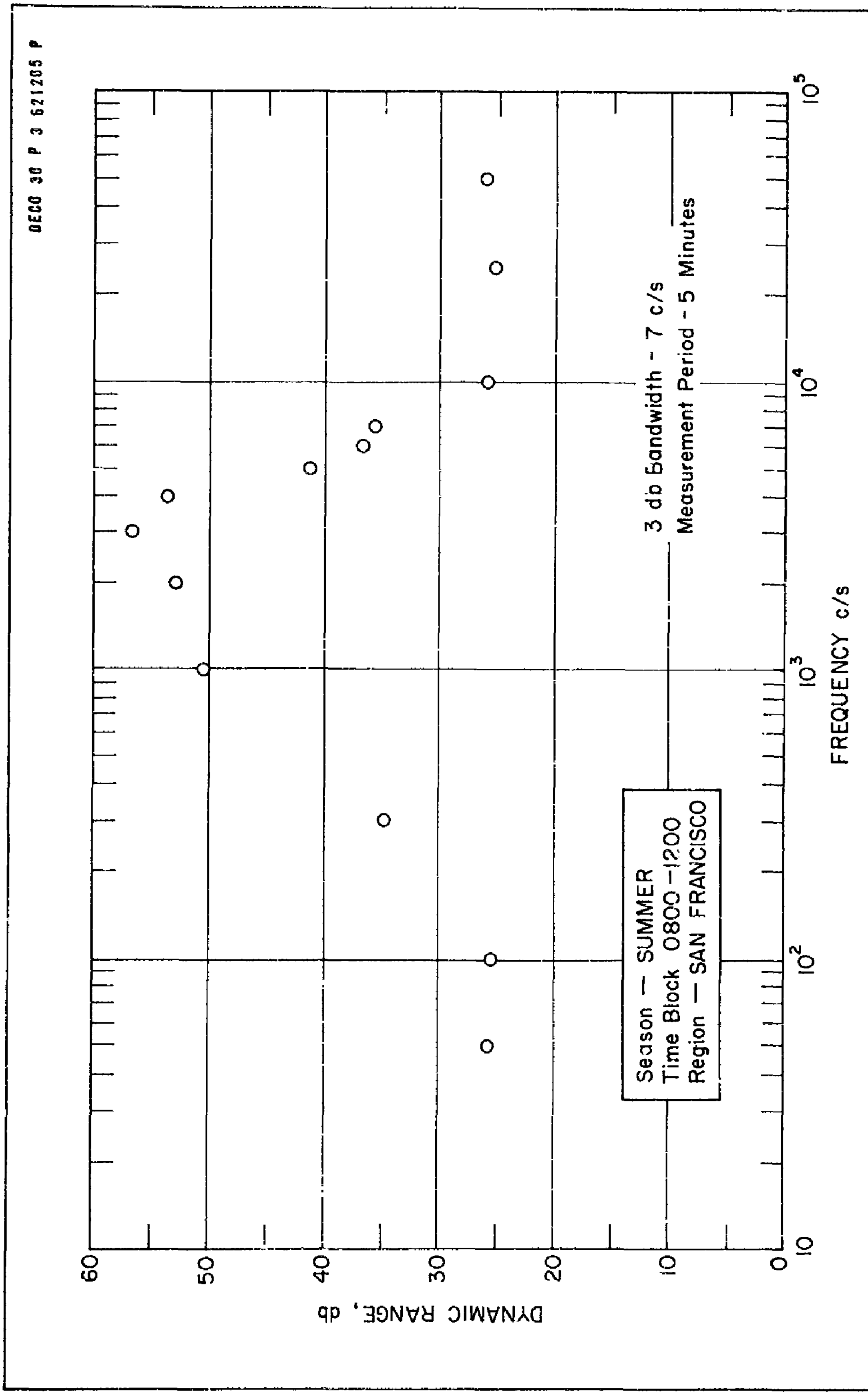

Figure 15 DYNAMIC RANGE; RMS TO PEAK ENVELOPE

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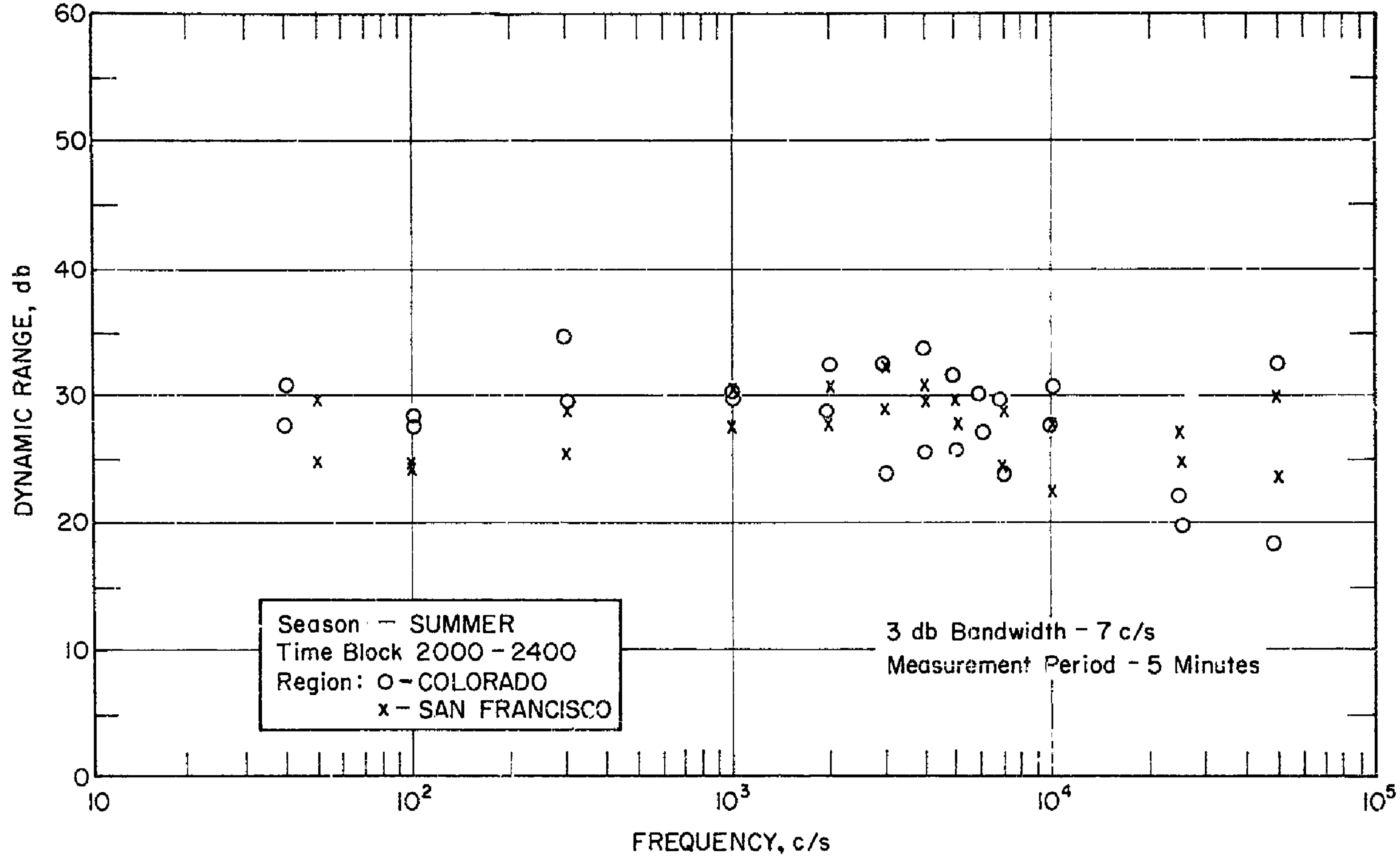

Figure 17 DYNAMIC RANGE; RMS TO PEAK ENVELOPE

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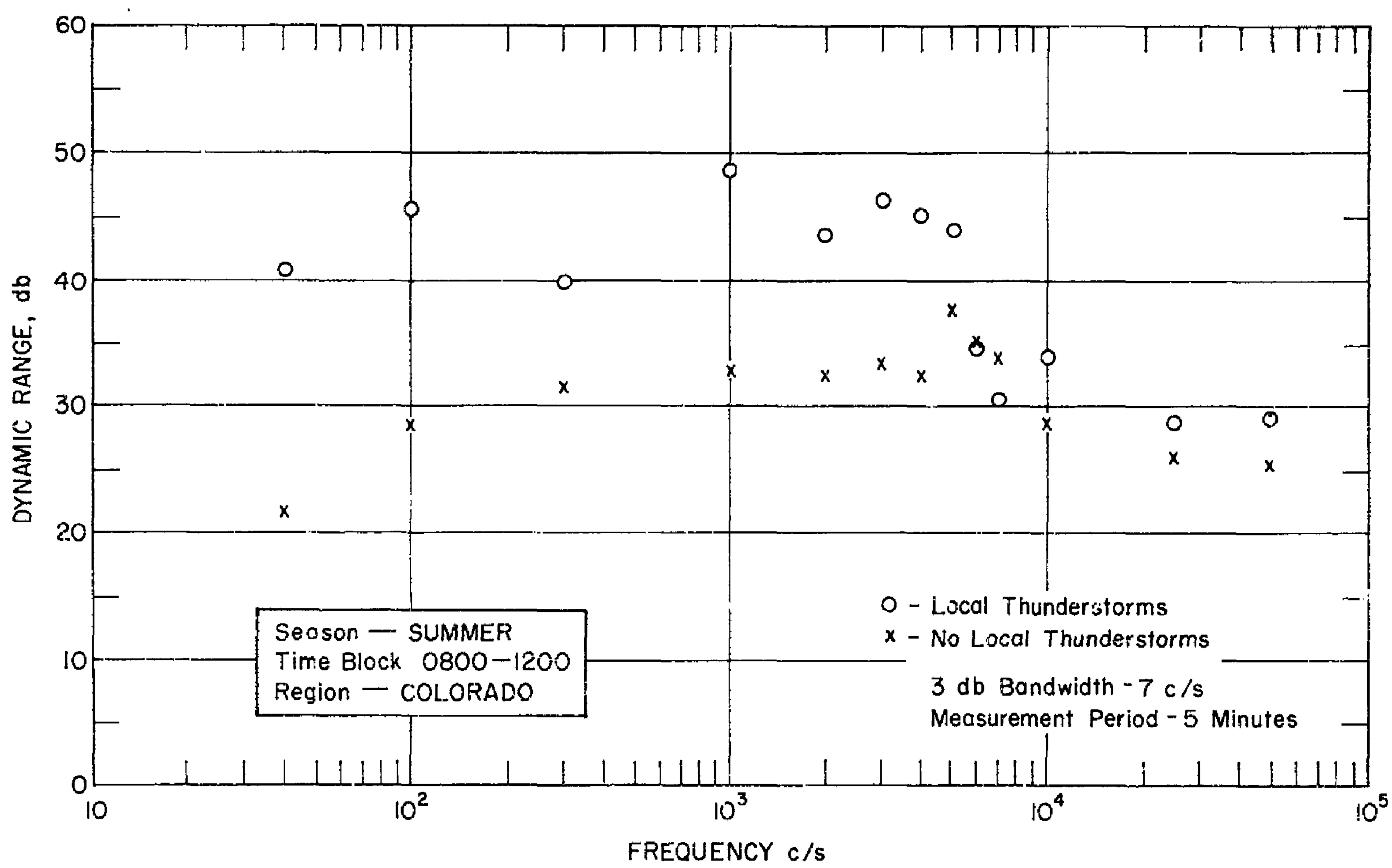

Figure 18 DYNAMIC RANGE; RMS TO PEAK ENVELOPE

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